5. HIGHLIGHTS OF LABORATORY ACTIVITIES IN 2005

This section highlights the Laboratory's accomplishments for 2004 with summaries written by the Branch Heads, which give examples of the research carried out by Branch scientists and engineers. The Branch highlights are supplemented by NASA press releases in Appendix A1, by abstracts of highlighted journal articles in Appendix A2, and by a complete listing of refereed papers that appeared in print in 2004, in Appendix A3. For more details on Branch science activities, the Branch Web sites can be accessed from the Laboratory for Atmospheres home page at http://atmospheres.gsfc.nasa.gov/.

5.1 Mesoscale Atmospheric Processes Branch, Code 613.1

The Mesoscale Atmospheric Processes Branch seeks to understand the contributions of mesoscale atmospheric processes to the global climate system. Research is conducted on the physical and dynamical properties and on the structure and evolution of meteorological phenomena, ranging from synoptic scale down to microscales, with a strong focus on the initiation, development, and effects of cloud systems. A major emphasis is placed on understanding energy exchange and conversion mechanisms, especially cloud microphysical development and latent heat release associated with atmospheric motions. The research is inherently focused on defining the atmospheric component of the global hydrologic cycle, especially precipitation, and its interaction with other components of the Earth system. Branch members participate in satellite missions and develop advanced remote sensing technology with strengths in the active remote sensing of aerosols, water vapor, winds, and convective and cirrus clouds. There are also strong research activities in cloud system modeling, and in the analysis, application, and visualization of a great variety of data.

Branch scientists develop retrieval techniques to estimate precipitation using satellite observations from TRMM and other satellites such as GOES and the AMSR-E sensor on EOS Aqua. The major accomplishments this year were in the areas of TRMM algorithm improvement and achieving continued operation of the TRMM satellite. In particular, there were significant publications on the latent heating data product. The accuracy of the TRMM algorithms continues to improve. The TRMM Ground Validation team supports this achievement through processing and analysis of data from rain gauge networks and ground-based radars. Six years of high quality data are now available through the Goddard DAAC. TRMM and other precipitation data are used within the Branch for a wide spectrum of studies on precipitating cloud systems and the global water cycle. Increasingly, these activities integrate global or regional data sets with modeling. Research is conducted on the assimilation of TRMM observations into models to explore the potential benefits to weather forecasting, such as for hurricanes, and to improve understanding of precipitating cloud systems. Branch scientists are also an integral part of the developing Global Precipitation Measurement (GPM) mission. Significant progress has been achieved in formulating this mission including incorporation of high-frequency channels for the GPM Microwave Imager (GMI) to improve light rain and snowfall measurement capabilities. Various NASA and international workshops and meetings were held to advance the formulation of the mission and validation program.

Development of lidar technology and application of lidar data for atmospheric measurements are also key areas of research. Systems have been developed to characterize the vertical profile structure of cloud systems (CPL), atmospheric aerosols (MPLNET), water vapor (SRL and RASL), and winds (GLOW) at fine temporal and/or spatial resolution from ground-based or airborne platforms. In addition, CPL and the CRS, a millimeter-wavelength radar for profiling cloud systems, have been integrated on NASA's high altitude WB-57 research aircraft for use in sensing the microphysical properties of cirrus and other cloud types. These systems will participate in field campaigns to validate NASA's Aura satellite, and CloudSat and CALIPSO.

A major accomplishment in 2005 was the success of three IIP proposals. These were: TWiLiTE, an airborne direct detection Doppler lidar to measure wind profiles through the troposphere (0–17 km) using the laser signal backscattered from molecules; HIWRAP, a conical scanning Doppler radar to provide horizontal winds within precipitation and clouds, and ocean surface winds in addition to more traditional 3-D radar reflectivity and hydrometeor characteristics; and the Airborne Water, Aerosol, Cloud, and Carbon Dioxide Lidar—an Airborne Raman Lidar to simultaneously profile water vapor mixing ratio, aerosol backscattering, extinction and depolarization, and cirrus cloud properties, as well as cloud liquid water and carbon dioxide concentration. Development of these exciting new capabilities presents a major challenge.

Initial papers on results from GLAS were published in a special issue of GRL and elsewhere on topics ranging from applications to global circulation models, to ocean surface signals. Improvements in data processing algorithms continued. In addition, an improved technique for infrared (IR) stereo cloud retrievals including multiple layer analysis was demonstrated with data from the STS-85 shuttle mission of the Infrared Spectral Imaging Radiometer (ISIR) Uncooled Microbolometer Array Detector (UMAD) instrument. Final testing of the COVIR IIP instrument is ongoing.

The MPLNET project underwent a major expansion in 2005. There are currently 10 active sites in the network: 3 in the U.S., 3 in Asia, 2 in Antarctica, 1 in the Arctic, and 1 off the west coast of Africa. Data from several of the sites are publicly available on our Web site, and the remaining sites will soon be public after calibrations are completed. Older data sets from an additional 14 sites remain available. Planning is underway for future sites in 2006–2007, including additional sites in the U.S., Asia, and the west coast of Africa, and new sites in the Caribbean, South America, and the Middle East. MPLNET is preparing for validation of CALIPSO after launch (spring 2006) and will participate in the African Monsoon Multidisciplinary Analysis (AMMA) campaign later in 2006. MPLNET results were compared against competing techniques and were found to have one of the lowest bias errors of all the methods available. Profiles of aerosol extinction are a primary MPLNET data product and an important data product to validate CALIPSO. The paucity of aerosol profile data is a major source of uncertainty in assessing global and regional climate models.

The Raman Lidar group is engaged in a broad range of research involving development and use of technologies for studying atmospheric processes including 1) Aqua and AURA satellite measurement validation; 2) development of an airborne Raman Lidar with the ability to profile water vapor, aerosols, clouds and other quantities during both day and night; and 3) development of the capability to remotely quantify aerosol physical properties using multi-wavelength Raman lidar. Two University of Maryland Baltimore County (UMBC) Ph.D. graduate students and one Ph.D. graduate student from University of Maryland College Park (UMCP) are supported and two visiting scientists from Brazil are currently working with the group. There is also substantial interaction with Howard University (HU) graduate students at the HU Beltsville Research Campus.

The branch is active in the development and application of atmospheric modeling systems. Three major development efforts were achieved in the past year. The NASA fvGCM and GCE model, a cloud-resolving model, were coupled in a multiscale modeling approach. The use of the fvGCM allows global coverage, and the GCE model provides explicit simulation of cloud processes and their interactions with radiation and surface processes, in contrast with conventional parametric approaches. This modeling system has been applied and tested for two different climate regimes, El Niño (1998) and La Niña (1999). The new coupled modeling system produced more realistic propagation and intensity of tropical rainfall systems and intraseasonal oscillations, which are very difficult to forecast using conventional GCMs. A second major effort involved coupling various NASA Goddard physical packages (microphysics, radiation, and land surface models) into a next generation weather forecast model (called weather and research forecast model, or WRF). The new coupled modeling system allows better forecasting (or simulation) of convective systems and tropical typhoons. Lastly, an improved GCE modeling system has been developed at Goddard over the last two decades. The GCE model has been recently improved to simulate the impact of atmospheric aerosol concentration on precipitation processes, and the impact of land and ocean surface on convective systems in different geographic locations. The improved GCE model has also been coupled with the NASA TRMM microwave radiative transfer model and precipitation radar model to simulate the satellite observed brightness temperature at various frequencies. This new coupled model system allows us to investigate tropical cloud processes and improves the precipitation data retrieved from NASA satellites.

Branch scientists conducted research in the areas of hurricane formation, structure, and precipitation processes with an emphasis on storms that occurred during special NASA field programs such as CAMEX-4 and the TCSP experiment. Numerical forecast models, such as Mesoscale Model 5 (MM5) and WRF, were applied to simulate observed storms at very high grid resolution. The results were compared to field program and satellite (e.g., TRMM) measurements. Analysis of the results led to improved understanding of precipitation organization, storm structure, and their relationship to intensity change. Numerical models and TRMM satellite data are also used to study the organization of precipitation in winter storms, the mechanisms responsible for that organization, as well as climatological aspects of winter precipitation at lower mid-latitudes (approximately 24–35°N).

The impact of urbanization on precipitation variability was also explored. The impact of future urbanization on regional climate was investigated using a combination of an urban growth model (UrbanSim), MM5, and land surface model NOAH[1]. Major finds indicate that Houston urban land use in the year 2025 will significantly impact regional cloud and precipitation variability. Results suggest that runoff and potential urban flooding impacts will be elevated because of urban-enhanced convective events. TRMM-based and ground-based rainfall products were used to identify urban rainfall anomalies around Tokyo, Phoenix, Indianapolis, and other urban centers.

5.2 Climate and Radiation Branch, Code 613.2

One of the most pressing issues we face is to understand the Earth's climate system and how it is affected by human activities now and in the future. This has been the driving force behind many of the activities in the Climate and Radiation Branch. We have made major scientific contributions in five key areas: hydrologic processes and climate, aerosol–climate interaction, clouds and radiation, model physics improvement, and technology development. Examples of these contributions may be found in the list of refereed papers in Appendix 2 and in the material on the Code 613.2 Branch Web site, http://climate.gsfc.nasa.gov.

Besides scientific achievements, we have made great strides in many areas of science leadership, as well as science enabling, education, and outreach. Thanks to the organizational efforts of Yoram Kaufman and Lorraine Remer, the AeroCenter seminar series continues to run well and is very well attended. The biweekly seminars overflow the meeting room and attract aerosol researchers from NOAA and the University of Maryland on a regular basis. Collaborative papers between AeroCenter members from different disciplines are now commonplace. Previous AeroCenter visitors submit papers based on the work done during their visits to Goddard.

MODIS data have been used for quantitative assessment of the emission, transport, and fate of dust from Africa. The MODIS data shows, in agreement with chemical transport models, that 120 Tg of dust are deposited annually into the oceans. It also resolves an old paradox about the need of Saharan dust as the main fertilizer of the Amazon basin and the amount of dust that was calculated to arrive in the Amazon region. Evidence was found that heavy smoke in the Amazon significantly reduces formation of boundary layer cumulus clouds and can change the smoke forcing from net cooling to net warming for which a paper was published in *Science*. A strong collaboration has been established with the Environmental Protection Agency (EPA) and with NASA/Langley Research Center for the purpose of air quality monitoring and forecasting. As part of NASA's Applications effort (Code YO) the potential of using the MODIS aerosol products as a Decision Support Tool within the EPA's Air Quality Decision Support System has been demonstrated. The availability of MODIS cloud and aerosol products has opened many new pathways of research in climate modeling and data assimilation in the

1. NOAH is a nested acronym defined as the **N**ational Centers for Environmental Prediction (NCEP), **O**regon State University (Dept. of Atmospheric Sciences), **A**ir Force (both AFWA and AFRL—formerly AFGL, PL), **H**ydrologic Research Lab of the NWS (now Office of Hydrologic Development)

Laboratory. In recognition of his leadership in aerosol research, in 2004 Yoram Kaufman was elected a Fellow of the American Meteorological Society (AMS).

We continue to serve in key leadership positions on international programs, panels, and committees. Si-Chee Tsay leads a group of scientists from NASA and universities in initiating a new project—Biomass-burning Aerosols in South East-Asia: Smoke Impact Assessment (BASE-ASIA), to study the effects of smoke aerosol on tropospheric chemistry, water and carbon cycles, and their interactions in the Southeast Asia monsoon region, using multiplatform observations from satellites, aircraft, networks of ground-based instruments, and dedicated field experiments. Robert Cahalan serves as project scientist of SOlar Radiation and Climate Experiment (SORCE) launched January 25, 2003. SORCE is measuring both Total Solar Irradiance (TSI, formerly "solar constant") and Spectral Solar Irradiance (SSI) with unprecedented accuracy and spectral coverage (1–2000 nm for SSI, 1–100,000 nm for TSI) during a 5-year nominal mission lifetime. Cahalan is also chairing the Observations Working Group of the Climate Change Science Program Office, tasked to evaluate and coordinate multiagency contributions to the U.S. Government climate observing system. He also chairs the 3-Dimensional Radiative Transfer Working Group of the International Radiation Commission and directs the International Intercomparison of 3-Dimensional Radiation Codes. In recognition of his long-standing leadership in radiative transfer, during 2004, Warren J. Wiscombe of the Climate and Radiation Branch was elected President of the Atmospheric Sciences Section of the American Geophysical Union (AGU).

The Climate and Radiation Branch Web site (http://climate.gsfc.nasa.gov) has a front page that changes almost daily. It provides the latest news in climate research and automatically updates the calendars of users who subscribe. Its "Image of the Week" highlights research by Branch members. A search page provides easy access to archived news, images, publications, and other climate information and data. The Branch Web site also has an extensive glossary of Earth science acronyms and a list of links to related sites. The Earth Observatory Web site (http://earthobservatory.nasa.gov) also continues to provide the science community with direct communication gateways to the latest breaking news on NASA Earth Sciences. It provides the news media and other communications outlets with a "one-stop shopping" resource for publication-quality images and data visualizations from NASA Earth Science satellite missions such as Terra, Aqua, and many others. The Earth Observatory Web site now boasts over 27,000 subscribers, with roughly 1 million page views per month worldwide. The contents of the Web site are increasingly syndicated by NASA Headquarters and other public sites.

In 2005, several key new findings have arisen from branch research. MODIS aerosol products now enable forecasting air quality, based on a NASA-EPA partnership. MODIS global annual direct aerosol radiative forcing over clear sky oceans is estimated to be -5.3 ± 0.6 W m^{-2}. For the NE Pacific, aerosols enhance radiative cooling by -7 W m^{-2} for overcast conditions. Evolution of aerosol over land and water surfaces is being tracked using combined Terra-Aqua data. Smoke from African fires increases cloud coverage by ~ 0.1 while reducing cloud droplet size.

A new method to measure aerosol absorption from space has been developed. The method measures aerosol attenuation of sun glint over the ocean to derive aerosol absorption. The method will be best applied to future satellites that can measure the same spot over the ocean at an angle at glint and at an angle off glint. A method to simultaneously analyze measurements from a two-wavelength lidar and a passive spectroradiometer, such as MODIS, has been introduced. The MODIS data are used to constrain the lidar inversion, thus decreasing the weight of assumptions in retrieving the aerosol profiles. The method was applied to Saharan dust and smoke from Africa in two field experiments.

The new MODIS "collection 5" level-2 operational cloud algorithm includes pixel-level uncertainties and multilayer cloud detection for thin upper-layer clouds. Alexander Marshak is an editor (together with A. Davis from Los Alamos) of the "Three-Dimensional Radiative Transfer for Cloudy Atmospheres" monograph being published by Springer-Verlag. He also has authored and coauthored three chapters in the book. Two additional chapters were authored by R. Cahalan and W. Wiscombe. The 3rd Intercomparison of 3D Radiation Codes (I3RC) workshop took place on a boat on the Baltic Sea, with branch members R. Cahalan and A. Marshak leading this international coordination of 3-dimensional radiative transfer activities.

Major Field Operations led by the branch include BASE-ASIA and the United Arab Emirates Unified Aerosol Experiment (UAE[2]), deployments of SMART-COMMIT. Warren Wiscombe became Chief Scientist of the DOE/ARM Program. An ARM "thermometer" was developed to measure for cloud liquid water. At the Williamsburg Aerosol Strategy Meeting, the CLAIM-3D concept was recommended to become a NASA HQ directed mission. New 3-D radiative transfer results have demonstrated CLAIM-3D's potential for retrieving cloud droplet vertical profiles. IUGG-2007 Joint Symposium on 3DRT (3-D Radiative Transfer), co-sponsored by IAMAS[1], IAHS[2], and ICCS[3], to be convened by R. Cahalan, with co-convener B. Mayer of DLR[4]. The THOR Lidar System has validated precise measurements of the thickness of 1 km thick clouds, to a precision of 50 m. THOR is now being modified for measurement of ice and snow thicknesses.

Six years of TRMM data show a weekly cycle: over the continental U.S. in summer, rain intensity and area increase midweek when pollution is at its maximum; with opposite behavior over nearby waters. This finding provides new potential for determining the influence of human activities on rainfall.

A new activity that is now being co-hosted by the Climate and Radiation Branch and the Goddard Solar Physics Branch is the Goddard Sun–Climate Center. The Sun–Climate Center, like the AeroCenter, is a crosscutting activity within Goddard's Sun–Earth Exploration Directorate. The Center sponsors research on solar system climate, and investigates new opportunities for advancing the understanding of the Sun's forcing of Earth's climate. Visiting scientists from Germany and Japan have recently joined this effort, and the Center receives advice from an international panel of experts. The Center will sponsor a seminar series, and will encourage new collaborations between scientists studying Earth, the Sun, and Earth's Moon. See http://sunclimate.gsfc.nasa.gov

5.3 Atmospheric Chemistry and Dynamics Branch, Code 613.3

The Atmospheric Chemistry and Dynamics Branch develops computer models and remote sensing instruments and techniques as aids in studies of aerosol, ozone, and other trace gases that affect chemistry, climate, and air quality on Earth. Using satellite, aircraft, balloon, and ground-based measurements, coupled with data analysis and modeling, Branch scientists have played a key role in improving our understanding of how human-made chemicals affect the stratospheric ozone layer.

Branch scientists have been active participants in satellite research projects. In the late 1960s, our scientists pioneered development of the backscattered ultraviolet (BUV) satellite remote sensing technique. Applying this technique to data taken from NASA and NOAA satellites, Branch scientists have produced a unique long-term record of the Earth's ozone shield. The data record now spans more than three decades, and provides scientists worldwide with valuable information about the complex influences of Sun, climate, and weather on ozone and ultraviolet radiation reaching the ground. Branch scientists expect to maintain this venerable record using data from a series of BUV-like instruments that are planned for use on U.S. and international satellites in the next two decades. Branch scientists were also instrumental in developing the UARS project, which generated data used by researchers to produce a highly detailed view of the chemistry and dynamics of the stratosphere. Currently, Branch scientists are providing scientific leadership for the EOS Aura satellite, which was launched on July 15, 2004. Aura contains four advanced instruments to study the stratospheric ozone layer, chemistry and climate interactions, and global air quality. Branch scientists are also involved in the design of instruments,

1. International Association of Meteorology and Atmospheric Sciences
2. International Association of Hydrological Sciences
3. International Conference on Conceptual Structures
4. *Deutsches Zentrum für Luft und Raumfahrt* (German Aerospace Center)

algorithms, and data systems for the new generation of ozone sensors on the operational weather satellites (NPP and NPOESS) and are developing state-of-the-art instruments to monitor air quality and tropospheric chemical species from spacecraft located at high vantage points (at distances ranging from 20,000–1,500,000 km from Earth). In addition, they operate a suite of advanced active and passive remote sensing instruments to study the chemical composition of the Earth's atmosphere from ground and aircraft. The branch has recently developed an advanced instrument and algorithm capability for ground-based validation of OMI satellite aerosol, NO_2, SO_2, and O_3 data.

The measurement activities of the Branch are highly coupled with modeling and data analysis activities. The Branch maintains state-of-the-art 2-D and 3-D chemistry models that use meteorological data, produced by the GMAO, to interpret global satellite and aircraft measurements of trace gases. Results of these studies are used to produce congressionally-mandated periodic international assessments of the state of the ozone layer, as well as to provide a strategic plan for guidance in developing the next generation of satellite and aircraft missions. A major new thrust of the Branch is to apply the unique synergy between Branch modeling and measurement groups, which proved very successful for the study of stratospheric chemistry, to study chemically and radiatively active tropospheric species, including aerosol, CO_2, O_3, CO, NO_x, and SO_2, which effect climate, air quality, and human health.

The following provides more detailed descriptions of some of the current Branch activities:

3-D Stratospheric Chemistry Model Studies

Branch scientists are analyzing a series of chemical transport model simulations of stratospheric ozone chemistry. These results are being compared with long-term data records from satellites and ground-based instruments. The goal is to use the model results to draw inferences about long-term ozone trends due to decrease in stratospheric chlorine and anticipated changes in the global climate.

The Branch is working collaboratively with the GMAO to couple chemistry to the dynamics in their general circulation models for chemistry–climate studies. The stratospheric chemistry used in the chemistry-transport studies has been coupled to the GEOS 4 GCM. The resulting chemistry-climate model has been integrated for 55 years simulating the period from 1950 through 2004. Time-slice simulations with repeating conditions for 1980, 2000, and 2020 have been run for 25 years each. These simulations are directed at understanding the role of ozone in climate change over the coming decades and the role of climate change in modifying the response of ozone to CFCs.

Global Modeling Initiative (GMI)

The goal of GMI is to develop and maintain a state-of-the-art modular 3-D CTM that can be used for assessing the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry, including the effects of aircraft. The GMI model also serves as a testbed for model improvements.

The GMI CTM has options for several chemical mechanisms for studying different problems. Recently, we have added a combined tropospheric-stratospheric mechanism for investigations of the climatically sensitive upper troposphere/lower stratosphere, and a microphysical aerosol mechanism for the study of aerosol size distributions and their role as cloud condensation nuclei. The chemical mechanisms have been recoded for compliance with the ESMF. The sensitivity of the aerosol model results to meteorological input was evaluated by GMI team members at the University of Michigan. The GMI tropospheric model participated in an IPCC photochemical intercomparison which investigated model sensitivities to simulation of tropospheric ozone. An important aspect of all GMI studies is the evaluation of the credibility of model results using ground-based, aircraft, and remotely sensed measurements. Several papers comparing GMI results with observations are currently in preparation.

OMI Data Analysis

The OMI, built by Dutch/Finnish collaboration, was launched on NASA's EOS Aura satellite in July 2005. The primary objective of OMI is to continue the long-term record, created by the Branch scientists, of total ozone, tropospheric ozone, UVB, aerosols (primarily smoke and desert dust), and volcanic SO_2 using data from NASA's TOMS instrument series. OMI is also designed to measure several other trace gases important for air quality studies, including NO_2, anthropogenic SO_2, and BrO, with improved spatial and temporal resolution compared to data from previous instruments (the Global Ozone Monitoring Experiment [GOME] and SCIAMACHY) on European satellites. Several Branch scientists are members of a NASA-funded U.S. science team, which is led by Dr. Pawan K. Bhartia, the Branch Head. In 2005, the Branch scientists developed and released several TOMS-like data products from OMI. Preliminary analysis shows that these data are of better quality and have significantly greater accuracy and precision than that from TOMS, particularly for SO_2. Several new products, not previously available from TOMS, have also been produced and are currently being validated. Several scientific papers describing this work will appear in the journals in 2006.

Global Aerosol Studies

Aerosol radiative forcing is one of the largest uncertainties in assessing global climate change. To understand the various processes that control the aerosol properties and to understand the role of aerosol in atmospheric chemistry and climate, the Branch scientists have developed the GOCART model. In the past few years, the GOCART model has been used to study tropospheric aerosol and its effect on air quality and climate forcing. Major types of aerosol particles are simulated, including sulfate, dust, black carbon, organic carbon, and sea salt. Among these, sulfate, and black- and organic carbon mainly originate from human activities, such as fossil fuel combustion and biomass burning. Dust and sea salt are mainly generated by natural processes such as the uplift of dust from deserts by strong winds.

The modeling activities have been strongly connected to the satellite and aircraft observations. Our recent research involves studies of intercontinental transport of dust and pollutants using a combination of models and data. The data is from satellite observations (MODIS, MISR, and TOMS), ground-based network (AERONET), and *in situ* measurements (Aerosol Characterization Experiment–Asia [ACE-Asia], surface measurements from EPA and Interagency Monitoring of Protected Visual Environments [IMPROVE] networks). The aerosol absorption in the atmosphere is based on the GOCART model and AERONET data, and the aerosol radiative forcing is based on assimilated products of the model and MODIS data. In addition, the model results are used by many groups worldwide for studies of air pollution, radiation budget, tropospheric chemistry, hydrological cycles, and climate change. The model has participated in the recent international project of Global Aerosol Model Intercomparison (AEROCOM) and played a major role in the new Climate Change Science Program (CCSP) reports on aerosol direct climate forcing.

Measurement and Modeling of Atmospheric Carbon Dioxide

Recent Laboratory progress in carbon cycle science has come in the areas of atmospheric transport modeling and instrument construction and testing. The atmospheric chemistry and transport model, used for calculating global CO_2 transport, has incorporated a land biosphere emissions model and satellite data-constrained biomass burning emissions to produce CO_2 fields that are closely tied to actual meteorology and emission events. The modeling group is actively participating in an international model intercomparison exercise, TransCom-C, which is aimed at improving models' ability to utilize upcoming space-based CO_2 observations, such as the Orbiting Carbon Observatory. We are also collaborating with the GMAO in a new effort to develop a carbon cycle data assimilation system. We are in a collaborative effort with the Hydrospheric and Biospheric Sciences Laboratory to develop an airborne CO_2 laser sounder under the IIP. The modeling effort will help to optimize the sounder measurement characteristics through observing system simulation experiments. A partner instrument, the ground-based laser CO_2 profiler, is also being developed in the Laboratory for Atmospheres. The laser profiler has recently achieved CO_2 detection in reflection from clouds and has made range-resolved measurements of aerosols at both the online and offline wavelengths. This is the final step in making range-resolved measurements of CO_2 within the planetary boundary layer. The real-time CO_2 observations will be compared with modeled distributions to improve our knowledge of the coupling between carbon cycle processes and climate change.

Sun–Earth Connection Studies

Branch members were involved in several investigations into the influence of the Sun on the Earth's atmosphere. One study published in 2005 involved the effect of the very large solar storms in October–November 2003 on the middle atmosphere. The solar proton event of October 28–31, 2003 was the fourth largest of the past 40 years and caused huge NO_x (N, NO, NO_2) enhancements measured by the HALOE instrument and significant ozone depletions measured by the SBUV/2 instrument in the middle atmosphere. Another published study focused on the impact of all solar proton events in the years 2000–2003 on the middle atmosphere. This work showed polar total ozone depletions >1% lasting for several months past three of the event periods because of the large NO_x increases due to the intense flux of solar protons.

New Instrument Development

Two new instruments are nearing completion under the IIP, the Solar Viewing Interferometer Prototype (SVIP) and the GeoSpec (Geostationary Spectrograph). The SVIP is a 1.3 m prototype of an 8 m instrument that will make measurements between 1–4 μ to determine the amounts of CO_2, H_2O, O_3, N_2O, and CH_4 in the Earth's atmosphere from a position at L2. The SVIP is designed for testing in the laboratory, outside at Goddard, and on a mountaintop. The GeoSpec is a dual spectrograph operating in the UV/VIS and VIS/Near-Infrared (NIR) wavelength regions to measure trace gas concentrations of O_3, NO_2, and SO_2, coastal and ocean pollution events, tidal effects, and aerosol plumes. GeoSpec is intended to support future missions in the combined fields of atmospheres, oceans, and land. GeoSpec is a collaboration of our Laboratory, The Pennsylvania State University, Washington State University, and Research Support Instruments. GeoSpec activities during the current year included final optical prescription and mechanical design, detector procurement, and breadboard assembly plans. Initial testing of the prototype instrument is planned for spring 2006 with validation deployment during the summer at Washington State University.

A commercial Brewer double-grating spectrometer has been modified for nearly continuous measurement of column aerosols, NO_2, and SO_2, by the direct-Sun technique. This instrument has traditionally been used for measurements of total ozone and UV irradiance. Polarization and multiangle measurement capabilities have been added to test the possibility of deriving ozone profiles, as well as particle size and refractive indices of aerosols in the UV. The technology is being transferred to other Brewers around the world to form a network for satellite data validation.

An imaging polarimeter-spectrometer instrument is being developed using internal research and development funds to measure aerosol plume height from space using a passive remote sensing technique developed by the Branch scientists.

A new aircraft-based measurement program was started in 2005. ACAM was test flown onboard the NASA WB-57 during the AVE in June of 2005 flying out of Houston, Texas. This system combines high resolution photographic imagery of both nadir and forward-looking cloud conditions with nadir UV and VIS spectographic measurements in order to map trace gas concentrations of NO_2, O_3, and aerosols. These measurements will be used to validate similar measurements from the OMI onboard Aura. The tests flights were successful and led to instrument improvements that have been implemented for the CR-AVE mission in February of 2006.

5.4 Laboratory Highlights

Biomass-Burning Aerosols in South East Asia: Smoke Impact Assessment (BASE-ASIA)

Recent studies reveal that large scale biomass burning appears to have an impact on regional climate. Aerosols produced by biomass burning play an important role in determining cloud lifetime and precipitation, hence, altering the regional to global scale radiation and water budgets. The climatology of Southeast Asia is very different from that of Africa and South America. Large scale biomass burning in Southeast Asia causes smoke to interact extensively with clouds during March and April when fires are normally set. Smoke plumes generated from these fires can stretch hundreds of kilometers downwind of the fires. NASA scientists in the Laboratory for Atmospheres (led by Dr. Si-Chee Tsay) are interested in conducting in-depth observations to evaluate the effects of biomass-burning aerosols on aerosol-cloud interactions. Accurately assessing the impact of smoke aerosols requires continuous observations from satellites and networks of ground-based instruments as well as dedicated field experiments utilizing aircraft and ground-based instruments. NASA and the Chulalongkorn University (CU), Thailand, share an interest in strengthening research and education in Earth Sciences by utilizing spaceborne, airborne, and ground-based observations. The Letter of Agreement between NASA and CU has been signed to jointly conduct the BASE-ASIA research project and educational activities from 2006 to 2009.

The objectives of BASE-ASIA are: (1) to characterize and assess the impact of biomass-burning aerosols on Southeast Asian monsoon onset and precipitation (or fresh water distribution) patterns, (2) to understand the effects of biomass-burning aerosols on remote sensing observations, and (3) to provide educational opportunities for regional scientists and graduate students who desire additional training and research experience. Air and ground observations from Thailand during the studied period will be coordinated with data received during the same time periods from NASA's Terra, and A-Train satellites and other satellite data sets of Southeast Asia. The study areas are the Kingdom of Thailand and possibly the vicinity of the Association of South East Asian Nations (ASEAN), members of which include Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. For further information, contact Si-Chee Tsay (Si-Chee.Tsay-1@nasa.gov).

Developments in 3D Radiative Transfer

The Third I3RC workshop was held October 11–14, 2005 at the Leibniz-Institute of Marine Sciences at the University of Kiel (Germany) and partly onboard the vessel *Color Fantasy*. Climate and Radiation Branch members (Robert Cahalan, Alexander Marshak, Lazaros Oreopoulos, and T.Varnai) were among the main organizers of the workshop. This was the third I3RC workshop; the first two workshops were both held in Tucson, Arizona in 1999 and 2000. The I3RC is an international project that compares the performance of 3D radiative transfer codes used in a variety of scientific applications in the atmospheric sciences. I3RC participants come from more than 30 research groups based in several countries. The project is sponsored by the GEWEX Radiation Panel and the International Radiation Commission, and has been jointly funded by the DOE Atmospheric Radiation Measurements Program and by the NASA Radiation Sciences Program.

Goddard's Climate and Radiation Branch delegated six scientists to give presentations at the workshop: Robert Cahalan, Alexander Marshak, Vanderlei Martins, Lazaros Oreopoulos, Tamas Varnai, and Guoyong Wen. L. Oreopoulos and T. Varnai chaired two sessions and A. Marshak also led the final discussion. T. Varnai and G. Wen presented two new I3RC cases, which are based on a broken cloud field observed by several instruments on the Terra satellite, and 3D spread of lidar pulses in optically thick clouds. In addition to the I3RC cases, publicly available 3D radiative transfer codes, approximation methods, cloud stochastic models, and 3D radiative transfer science, in general, were widely discussed. Forty-six people from 10 countries attended the workshop. The results of the workshop were summarized in the paper "New Directions in the Radiative Transfer of Cloudy Atmospheres" recently published in EOS. For further information contact Alexander Marshak (Alexander.Marshak@nasa.gov).

New Book on 3D Radiative Transfer Published

In August, a new book titled "3D Radiative Transfer in Cloudy Atmospheres" was published. Authored by leading 3D radiation scientists from around the world, this 700-page volume contains expert information on many aspects of this highly complex subject. Laboratory radiative transfer experts R. Cahalan, A. Marshak, and W. Wiscombe are among the authors of the book chapters.

For almost a century, scientists relied on simple one-dimensional models to approximate radiant energy exchange in climate simulations; solar and thermal radiation were only allowed to move vertically. This somewhat crude representation of the atmosphere's radiant energy balance was the best approach science had to offer at the time. In this new publication, developments in 3D cloud radiation during the past few decades are assessed and distilled into a textbook-like tutorial, paving the way for a change in the "business as usual" attitude toward 1D approaches.

"It is time to think of 3D theory as the gold standard in atmospheric radiative transfer, rather than as a perturbation of standard 1D theory," wrote authors A. Marshak (Code 613.2) and A. Davis in the preface of the book, for which they also served as editors.

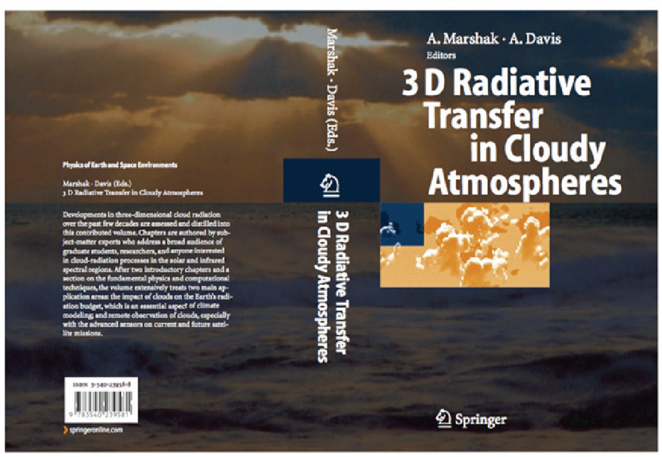

Figure 5.1. Developments in 3-D cloud radiation over the past few decades are assessed and distilled into this volume.

After two introductory chapters and a section on the fundamental physics and computational techniques, the book extensively treats two main application areas: the impact of clouds on the Earth's radiation budget, which is an essential aspect of climate modeling; and remote observation of clouds, especially with advanced sensors on current and future satellite missions. The book, funded in large part by the ARM Program, is written to satisfy a broad audience of graduate students, researchers, and others interested in cloud-radiation processes in the solar and infrared spectral regions. Published by Springer-Verlag (ISBN#3-540-23958-8). For further information contact Alexander Marshak (Alexander.Marshak@nasa.gov).

To see the first nine pages of this book, use the following URL to access the Web version of this report and click on the link given at the end of that section. http://atmospheres.gsfc.nasa.gov/reportsdocs/html/2005/06.php#3D

MODIS Data Processing

The MODIS Atmosphere Team is responsible for generating cloud, aerosol, and clear sky level-2 (pixel-level) and level-2 (gridded) products from the MODIS Terra and Aqua instruments. As a part of the latest MODIS Atmosphere Team reprocessing effort (referred to as "collection 5"), the GSFC level-2 cloud optical and microphysical properties algorithm (thermodynamic phase, optical thickness, effective size, water path) has been largely rewritten. In addition to a number of improvements, the updated algorithm includes new components that have never been incorporated into operational retrievals of this type, including: (1) Pixel-level uncertainties for optical thickness, effective particle size, and water path retrievals, along with estimates of the uncertainty in level-3 gridded means; (2) development of a set of spatially-complete surface spectral albedo maps derived from the MODIS land albedo product and used in modeling above-cloud spectral reflectances; (3) retrievals derived from novel spectral band combinations; and (4) a research-level multilayer cloud detection product. All level-2 retrievals from this algorithm are contained in the MOD06 and MYD06 product files (for MODIS Terra and Aqua, respectively). The algorithm is the responsibility of M.D. King (610) and S. Platnick (613.2), as are the entire set of MODIS Atmosphere Team level-3 (daily, eight-day, and monthly) algorithms.

Collection 5 reprocessing began production in December 2005 with Terra data; MODIS Aqua collection 5 reprocessing is expected to begin in late spring or early summer 2006. The team has developed an extensive Web site (http://modis-atmos.gsfc.nasa.gov/) that provides product documentation, browse imagery, and tools. In particular, documents are provided detailing individual Atmosphere Team collection 5 algorithm modifications, improvements, and impacts. All Atmosphere Team collection 5 products are being processed at GSFC by the MODIS Operations Data Processing System (MODAPS), and will be distributed through the associated MODIS Atmosphere Archive and Distribution System (AADS). The cloud optical and microphysical properties algorithm has also been made available to the University of Wisconsin International MODIS/AIRS Processing Package (IMAPP) team for use with direct broadcast data. For further information contact Steven Platnick (Steven.Platnick@nasa.gov).

CO_2 Lidar

Making range-resolved measurements of CO_2 within the lowest 3 km of the atmosphere can significantly enhance our understanding of what is happening to anthropogenically generated CO_2, an important greenhouse gas. These measurements enable the direction and magnitude of CO_2 fluxes to be determined, which help identify sources and sinks for the gas. In order to be scientifically useful, the measurement precision must be approximately 1 part in 380. Ground-based lidar observations are capable of providing continuous profiles of CO_2 through the planetary boundary layer and into the free troposphere. We have developed a prototype lidar based on components developed in the telecommunications industry. Our Differential Absorption Lidar (DIAL) approach measures absorption by CO_2 of pulsed laser light at 1.58 µm backscattered from atmospheric aerosols. Aerosol concentrations in the planetary boundary layer are relatively high and will be able to provide adequate signal returns for the desired resolution. Performance simulations indicate that an optimized lidar will be capable of providing continuous 10 min averaged profiles with 150 m vertical resolution and better than 1 ppmv precision at 1 km. Precision increases (decreases) at lower (higher) altitudes and is directly proportional to altitude resolution and acquisition time; thus, precision can be improved if temporal or vertical resolution is sacrificed. The long-term goal of the project is to develop a rugged, autonomous system using only commercially available components that can be replicated inexpensively for deployment in a monitoring network. For further information contact John Burris (John.F.Burris@nasa.gov).

Advances in TRMM Data Analysis

Methods of extracting the dependence of mean rainfall on the time of day have been developed for use with the TRMM data, now available from December 1997 to the present. The method provides not only estimates of the size of the day/night change, but also statistical confidence limits for the changes. The map shown in Figure 5.2 is an example of the information that can be provided for 5° grid boxes, with brightest colors (colors along the top of the color bar) indicating highest confidence in the daily changes. Note how over the oceans maximum rainfall tends to occur in the morning hours, whereas over land it occurs mostly in the afternoon hours. (Grid boxes with average rain rate below 0.01 mm/h have been masked.) For further information contact Tom Bell (Thomas.L.Bell@nasa.gov).

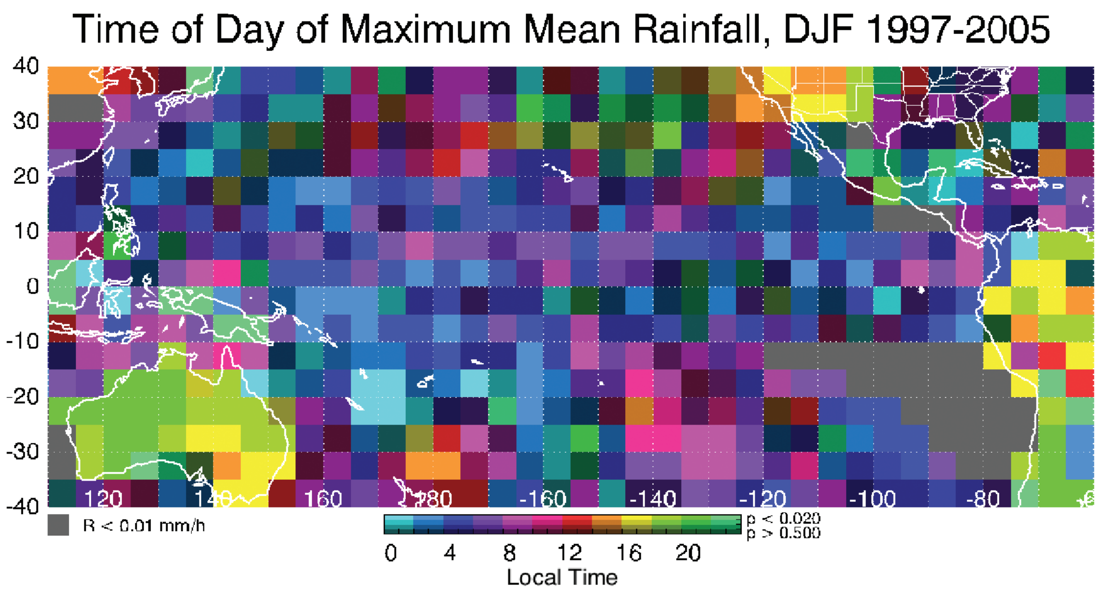

Figure 5.2. Nine year record of time from 1997–2005, of maximum rainfall during December, January, and February.

Radar-Based Wind Measurements from UAVs

While lidar-based tropospheric wind measurements are ideally suited for clear regions, the signal is strongly attenuated by clouds and precipitation. On the other hand, radar-based winds perform well in these regions and are, therefore, very complementary to the lidar measurements. Two separate efforts are being pursued for radar-based winds measurements in precipitation and cloud regions from UAV. The first effort, called UAV Radar (URAD), was started under Goddard IR&D funding. This radar is a conventional X-band radar that performs conical scan from a high-altitude UAV (HUAV). The conical scan provides a means to estimate the atmospheric horizontal winds and radar reflectivity structure in a three-dimensional grid point below the UAV. It also enables estimation of ocean surface winds in rain-free to light-rain regions through well-known scatterometry techniques. The second effort is funded under the NASA IIP and is called HIWRAP. This system also provides similar measurements to URAD, but it is dual-wavelength (Ku and Ka band) and dual incidence angle to provide higher accuracy in the wind measurements. In addition, HIWRAP uses more advanced technology with solid state rather than tube transmitter technology, pulse compression using digital receiver and Field Programmable Gate-Array (FPGA)-based processing. The technology being pursued under this effort also has application to space-based wind measurement. For further information contact Gerry Heymsfield (Gerald.M.Heymsfield@nasa.gov).

Effect of Smoke from African Fires on Shallow Cloud Cover

Clouds developing in a polluted environment tend to have more numerous, but smaller, droplets. This property may lead to suppression of precipitation and longer cloud lifetime. Absorption of solar radiation by aerosols, however, can reduce the cloud cover. The net aerosol effect on clouds is currently the largest uncertainty in evaluating climate forcing. Using large statistics of MODIS satellite data, we indicate, in Figure 5.3, the aerosol effect on shallow water clouds, separately in four regions of the Atlantic Ocean, for June through August 2002: marine aerosol (30°S–20°S), smoke (20°S–5°N), mineral dust (5°N–25°N), and pollution aerosols (30°N–60°N). All four aerosol types effect the cloud droplet size. We also find that the coverage of shallow clouds increases in all of the cases by 0.2–0.4 from clean to polluted, smoky, or dusty conditions. Covariability analysis with meteorological parameters associates most of this change to aerosol, for each of the four regions and 3 months studied. In our opinion, there is low probability that the net aerosol effect can be explained by coincidental, unresolved, changes in meteorological conditions that also accumulate aerosol, or errors in the data. For further information contact Steven Platnick (Steven.E.Platnick@nasa.gov).

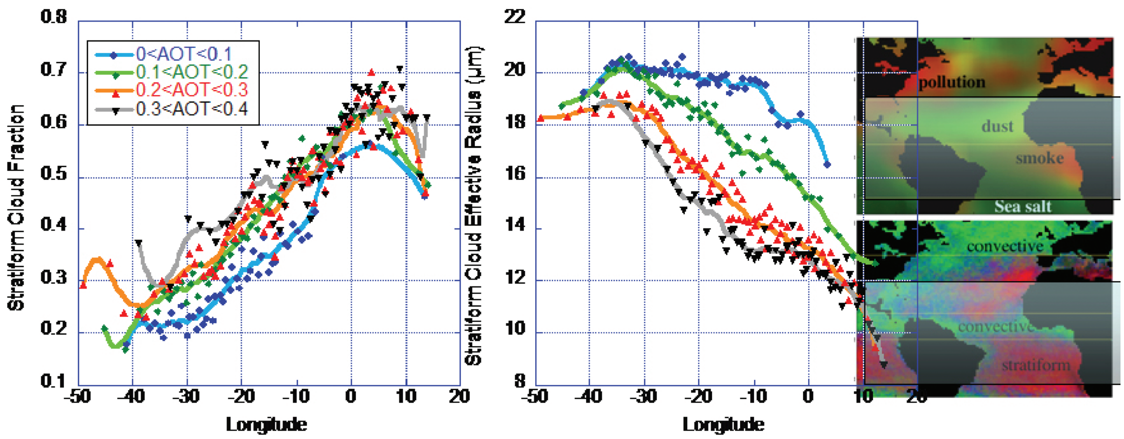

Figure 5.3. Smoke from fires in Africa increases cloud coverage by ~ 0.1 (left panel) while reducing the cloud droplet size (center panel). The effect is linked to smoke inhibition of precipitation and enhancement of the strength of the inversion. The right panel shows the distribution of aerosol and clouds over the Atlantic Ocean for June–August 2002. The upper panel indicates optical thickness, given by the image brightness, and type, given by color. The lower panel shows the distribution of shallow (red), deep convective (green), and mixed (blue) cloud cover. AOT is aerosol optical thickness.

Cloud-Aerosol Interaction Mission, CLAIM-3D

The effects of aerosols in clouds go all the way from changing Earth's radiative balance, to significant effects on changing precipitation patterns and the intensity of thunderstorms. CLAIM-3D is a proposed satellite mission designed to advance our understanding of cloud and precipitation development by measuring *vertically resolved* cloud microphysical parameters in combination with state-of-the-art aerosol measurements. The CLAIM-3D mission concept uses well-established space technology in a set of innovative measurements that allows simultaneous aerosol and cloud microphysics measurements. The proposed mission has a very unique combination of extended wavelength range (380–12,000 nm), polarization, and multiangle 3D observing geometry, combining properties of several previous satellite missions, as well as adding many new features never flown or even proposed before. It is designed to measure the vertical profile of cloud microphysical properties, and also to combine the best features from previous satellite projects (like the Polarization Detecting Environmental Radiometer [POLDER], MISR, MODIS, and OMI) to characterize aerosols and cloud microphysics with greater synergy than any previous mission. The mission will have flexibility in terms of pointing capability in order to focus on cloud types and regions of particular interest, and also to maximize proper illumination geometry for accurate retrievals of cloud microphysical parameters. The multiangle capabilities of CLAIM-3D (along and cross track) allow us optimized geometry to focus on very specific cloud structures and regions. The combination between polarization and high resolution multiangle capability also allows CLAIM-3D to measure "cloud droplet rainbows" or cloud bows, which are just like the rainbows that we see out of rain droplets (of millimeters to a fraction of millimeters in diameter), but now formed by much smaller cloud droplets (of a few micrometers in size). The cloud bow measurements will allow us to accurately measure the size of cloud droplets. This is very important for the understanding of cloud microphysical properties and the evolution towards precipitation. For further information contact Jose Martins (Jose.Martins.1@gsfc.nasa.gov),

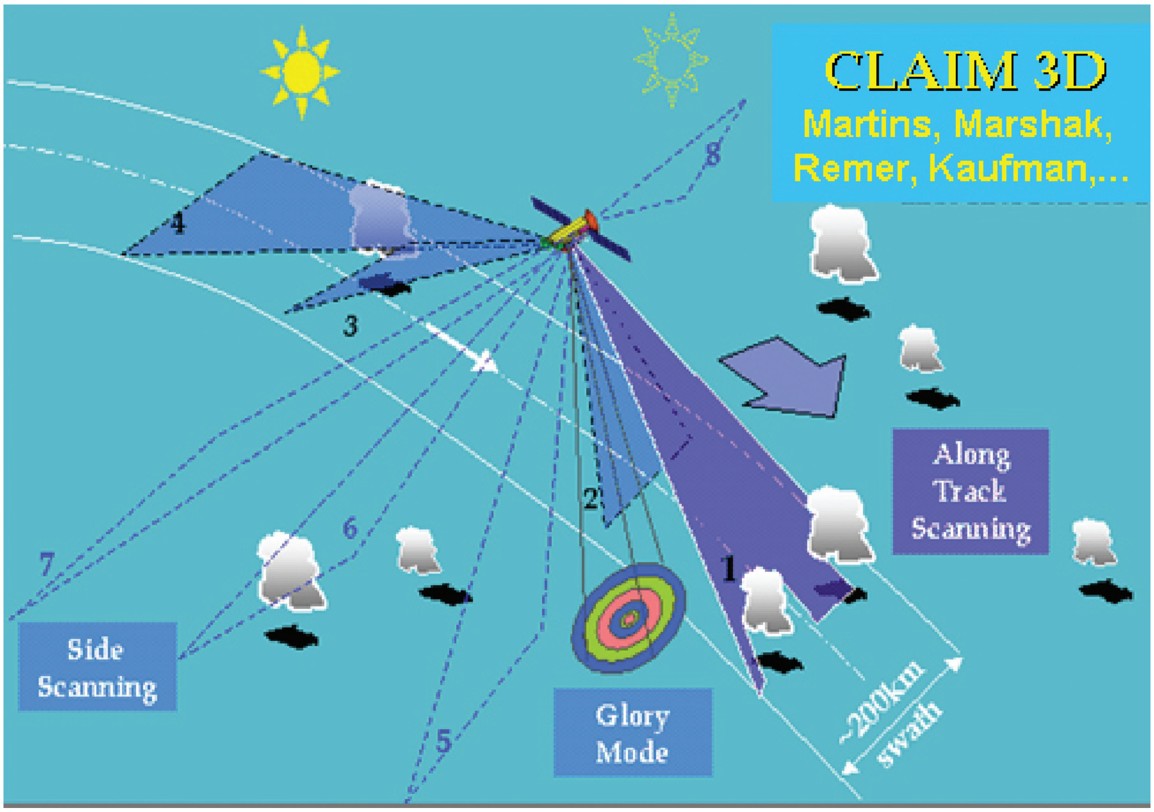

Figure 5.4. Schematic of CLAIM-3D observation modes.

5.5 Awards

5.5.1 Individual Awards

NASA Exceptional Achievement Medal

Dr. Mian Chin (613.3)
In recognition of the development of the GOCART model to study atmospheric aerosols and gas species and their impact on air quality and climate.

Dr. Yogesh Sud (613.2)
For truly pioneering scientific advances on land-surface parameterization and biospheric-atmospheric processes and their influence on the general circulation.

Barry M. Goldwater Award

On Thursday, June 9, Fritz Hasler, who recently retired from 613.1, was awarded the "Barry M. Goldwater Award" by the American Institute of Aeronautics and Astronautics, Inc. (AIAA) National Capitol Section, which includes about half of all AIAA members. This is a prestigious award that was started at Barry Goldwater's instigation. He was an avid space enthusiast and supporter. The award was presented by Dr. Mike Griffin, NASA Administrator, and past recipient of the same award.

IEEE Senior Member

The Institute of Electrical and Electronics Engineers (IEEE) elevated Chuck Cote to the grade of Senior Member, their highest professional grade.

Dr. Robert Cahalan (613.2)
Dr. Cahalan received an award for "Outstanding Leadership and Service" in recognition of his work as Chair of the Observations Working Group of the United States Climate Change Science Program. The award was presented by James Mahoney, Assistant Secretary of Commerce for Oceans and Atmospheres.

5.5.2 Group Achievement Awards

Aura Education Outreach Team
For implementation of an outstanding education and outreach effort to inspire the next generation of explorers.

Aura Project Science Team
For outstanding and innovative efforts in leading the Earth Observing System Aura Science Team, developing the Aura validation plan, and production of outreach materials.

SAGE Ozone Loss Validation Experiment (SOLVE)-II DC-8 Science Team
In recognition of exceptional scientific achievement during the highly successful SOLVE-II polar mission during the winter of 2002–2003.

Outstanding Teamwork Award

MODIS Aerosol Algorithm Team/Code 613—Lorraine Remer accepting for team.

Members of the team include: Allen Chu, Richard Hucek, Charles Ichoku, Richard Kleidman, Robert Levy, Rong-Rong Li, Vanderlei Martins, Shana Mattoo, and Bill Ridgway.

Excellence in Outreach Award

Earth Observatory Team/Code 613—Rob Simmon accepting for team.

5.5.3 Instrument Incubator Program (IIP)

The IIP supports NASA's Science Mission Directorate. The main purpose of the program is to identify, develop, and, where appropriate, demonstrate new measurement technologies to reduce the risk, cost, size, and development time of Earth observing instruments, and/or enable new observation measurements. Five Laboratory scientists were selected as PIs, co-investigators (Co-Is), or collaborators on awards made during 2005 under this program.

Bruce M. Gentry, Code 613.1
TWiLiTE:Tropospheric Wind Lidar Technology Experiment

Gerald M. Heymsfield, Code 613.1
High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

David N. Whiteman, Code 613.1
Airborne Water, Aerosol Cloud and Carbon Dioxide Lidar

Omar Torres, Code 613.3, is a Co-I with PI David J. Diner, Jet Propulsion Laboratory for *A High-Accuracy Spectropolarimetric Camera for Aerosol Remote Sensing from Space*

Warren Wiscombe, Code 613.2, is a Collaborator with PI Martin G. Mlynczak, Langley Research Center, on *In-situ Net Flux Within the Atmosphere of the Earth*

5.6 UARS

UARS was launched by the Space Shuttle *Discovery* (STS-48) on September 12, 1991.

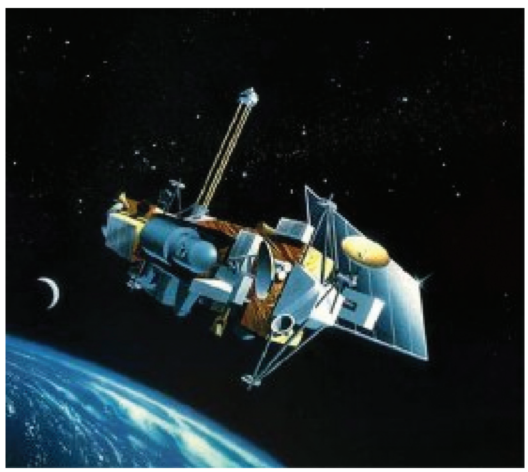

Figure 5.5. Artist's conception of UARS in orbit.

Although launched with a designed mission life of 18 months, UARS made comprehensive measurements of the upper atmosphere for more than 14 years. During this time, UARS provided many scientific accomplishments. Four examples of these follow:

1) Quantification of the relation between chlorine-containing constituents and ozone on a global scale in the stratosphere;
2) Quantification of the solar ultraviolet irradiance and total solar irradiance over more than a solar cycle (~14 years);
3) Quantification of the transport in the stratosphere, mesosphere, and lower thermosphere, including the first satellite measurements of winds in these regions;
4) Long-term (~14 years) measurement of several key constituents (ozone, HCl, HF, H_2O, CH_4, NO, and NO_2) in the stratosphere and mesosphere.

There have been over 1,000 papers published in refereed journals that use UARS observations. The study of these valuable measurements has resulted in a rewrite of our understanding of the physical processes acting within and upon the stratosphere, mesosphere, and lower thermosphere.

Figure 5.6. Cake presented at the UARS retirement party.

UARS was retired from service on December 14, 2005.